

Bridging Academia–Industry for Workforce Readiness: The Fault Analysis Certificate Program

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Abstract

The Fault Analysis Certificate Program is a workforce-focused initiative designed to bridge the gap between academic preparation and applied competencies required in modern power system operations. The program delivers a self-paced, unit-based curriculum integrating industry-standard simulation tools, anonymized real-world case studies, and co-developed instruction from academic faculty and practicing engineers. A multi-dimensional assessment framework evaluates conceptual understanding, applied analysis skills, learner confidence, and employer perspectives to capture both learning outcomes and workforce readiness impacts. With program launch scheduled for March 2026, preliminary evaluation evidence from the inaugural cohort will be incorporated into the final paper. Emphasizing career readiness, the certificate supports recruitment, onboarding, and professional advancement by equipping learners with practical fault analysis, protection, and reporting skills aligned with current operational and regulatory practices.

Keywords

Academia–Industry Collaboration, Certificate Program, Career Readiness, Fault Analysis, Power Engineering Education, Workforce Development

Introduction

The electric power sector is undergoing rapid transformation driven by increased grid complexity, high penetration of power-electronic interfaced resources, widespread deployment of synchronized measurements, and heightened expectations for reliability, resilience, and regulatory compliance [1], [2]. These trends have expanded both the volume and the criticality of disturbance and protection data available to system operators and engineers, placing greater emphasis on the ability to interpret fault records, diagnose system behavior, and communicate actionable findings across operational, planning, and compliance functions [3].

Fault analysis remains a core professional competency underpinning protection coordination, post-event forensics, restoration decision-making, and standards compliance. Engineers are increasingly expected to work within heterogeneous toolchains that combine digital fault recorders (DFRs), phasor measurement units (PMUs), protection relays, and enterprise data systems, while adhering to cybersecurity, access control, and data governance requirements defined by organizational policy and industry standards such as IEC 61850 and NERC reliability standards [4], [5].

In practice, fault analysis represents a highly specialized and cross-disciplinary role that integrates power system fundamentals, data analytics, computational workflows, and structured technical communication. Engineers must not only interpret system behavior but also translate findings into clear, actionable reports for operations, planning, and compliance stakeholders.

Despite this growing operational scope, fault analysis is frequently embedded as a limited topic within broader power system analysis or protection courses. Graduates may therefore enter the

workforce with strong theoretical foundations but limited exposure to end-to-end operational workflows, industry-grade software platforms, and authentic disturbance data. Employers subsequently face extended onboarding and reskilling timelines to prepare engineers for field-ready performance in low-inertia, renewable-rich, and data-intensive protection environments [2].

In response, the Fault Analysis Certificate Program was developed through a structured academia–industry collaboration to provide a focused, practice-oriented pathway that complements formal degree programs and supports both early-career engineers and experienced professionals. The program is intentionally designed to mirror professional workflows, from system access and data acquisition through technical diagnosis and formal reporting, thereby aligning educational depth with real-world relevance. This paper describes the program’s architecture, collaborative development process, assessment framework, and early implementation insights, with the goal of offering a replicable model for career-focused workforce training in power and energy engineering.

Background and Motivation

Workforce needs in power system operations

Utilities, system operators, and engineering firms increasingly seek engineers who can transition rapidly from academic preparation to operational effectiveness. Fault analysis plays a critical role in system restoration, reliability compliance, and regulatory reporting. Engineers are expected to interpret relay records, analyze fault waveforms, validate protection settings, and communicate findings across multidisciplinary teams.

Industry stakeholders have consistently identified a need for targeted training that goes beyond conceptual understanding and emphasizes decision-making in real operational contexts. This demand is further amplified by workforce turnover and the need to upskill professionals as grid architectures and protection technologies evolve.

Recent workforce trends also reflect a significant shift in experience levels within protection and operations teams. In some cases, average years of experience have decreased from multiple decades to only a few years, creating an urgent need for accelerated and standardized training pathways. This transition limits the availability of senior experts for sustained, one-on-one mentoring and increases reliance on structured, scalable training programs.

Limitations of traditional curricula

While undergraduate and graduate programs in electrical engineering provide foundational instruction in power systems, curriculum constraints often limit the depth of coverage dedicated to fault analysis. Laboratory experiences may rely on simplified models or preconfigured experiments that do not fully reflect the complexity of field conditions [6]. Additionally, access to industry-grade software and real operational data is often restricted.

These limitations motivate the development of supplemental, flexible training pathways that can integrate practical tools, real-world cases, and industry expertise into the learning experience.

Program Design and Architecture

The Fault Analysis Certificate Program is organized as a twelve-unit, workflow-driven curriculum that integrates conceptual foundations, applied diagnostics, and industry engagement across three complementary instructional layers: Section A (theoretical and systems foundations, prepared by academic faculty), Section B (event-based analysis and relay/DFR practice, prepared by industry engineers), and Section C (Industry Interview Series, providing practitioner perspectives from field, operations, and vendor roles). Together, these layers create a progressive learning pathway from physical fault mechanisms to professional-grade event reporting.

- **Unit 1: Power System Faults**

Establishes foundational knowledge of fault phenomena, including fault characteristics, symmetrical and asymmetrical faults, and sequence components. Learners examine the question “what is a fault?” in both physical and analytical terms, then apply these concepts through an industry-led fault analysis flowchart and waveform-based event examples covering single-line-to-ground, line-to-line-to-ground, and three-phase faults. The unit is complemented by an industry interview on professional fault analysis practice, reinforcing the connection between theory and field application.

- **Unit 2: Substation Monitoring Devices**

Introduces system protection equipment, including current and potential transformers, electromechanical and microprocessor-based relays, sampling rates, and digital fault recorders operating at kilohertz-scale resolution, as well as traveling-wave fault locators. Applied modules focus on interpreting diagrams, sequence of events records, and disturbance logs, supported by real substation event cases. The associated industry session highlights engineering practices in substation monitoring and diagnostics.

- **Unit 3: Generation Operations and Protection**

Expands the scope to protection zones, ANSI device numbers, and generation-side architectures, including synchronous generators, inverter-based resources, and flexible AC transmission devices such as Static Synchronous Compensators (STATCOMs) and Static Var Compensators (SVCs). Learners analyze generator and Generator Step-up Transformer (GSU) events, emphasizing relay functionality and fault behavior at the generation interface. Practitioner perspectives from plant operations reinforce operational constraints and coordination challenges.

- **Unit 4: Transmission Operations and Protection I**

Examines common transmission equipment, fault location calculation methods, resistive fault behavior, overhead versus underground line protection, and lightning correlation. Event-based learning centers on four-breaker ring configurations and real-world fault causes such as vegetation, animals, contamination, and lightning, enabling learners to link physical phenomena with relay behavior and system response.

- **Unit 5: Transmission Operations and Protection II**

Focuses on power transformers, inrush current theory, harmonic content, and power quality considerations. Learners investigate transformer disturbance records and fault events, analyzing how protection systems distinguish between inrush and internal faults, supported by practitioner-led transformer case studies.

- Unit 6: Transmission Operations and Protection III

Addresses voltage regulation, load tap changers, capacitor banks, and reactor banks. Event analysis includes both capacitor and reactor bank operations, emphasizing system stabilization, reactive power control, and protection coordination in transmission substations, reinforced by field-based substation engineering perspectives.

- Unit 7: Transmission Operations and Protection IV

Introduces communication-assisted protection schemes such as permissive overreaching transfer trip (POTT), directional comparison blocking (DCB), fiber-based relaying, powerline carrier, and pilot wire systems, alongside inverter-based resource islanding scenarios. Learners analyze differential and communication-based protection events, supported by industry expertise from protection relay vendors.

- Unit 8: Distribution Operations and Protection

Shifts focus to feeder-level systems, covering common distribution equipment, reverse and cross interlock schemes, feeder automation strategies such as fault location, isolation, and service restoration (FLISR), looped distribution networks, and fault-induced conductor motion. Learners evaluate complex distribution event cases, including bus lockout and capacitor bank protection, grounded in distribution field operations.

- Unit 9: Other Events Analysis

Addresses advanced and non-routine phenomena, including current transformer saturation, out-of-step conditions, open-phase events, nonhomogeneous line fault location challenges, pole disagreement, and subsynchronous oscillations. Learners examine abnormal potential events and misoperations through detailed overtrip case studies, guided by System Operations Center (SOC) perspectives.

- Unit 10: Substation Communication and Data Processing

Explores supervisory control and data acquisition (SCADA), file transfer protocols, IEC 61850 communication architectures, and time synchronization systems such as satellite clocks and C. Applied modules focus on substation data flows, enterprise communication pathways, and operational data processing, informed by data communications professionals.

- Unit 11: Data Gathering and Processing

Introduces virtualized digital fault recorder environments using dual virtual machines to emulate substations, automated record retrieval via File Transfer Protocol (FTP), scripting for file management, and extraction of auto-calculated fault locations from DFRs. Learners develop repeatable, enterprise-scale workflows for handling and validating disturbance data, emphasizing traceability and compliance.

- Unit 12: Event Summary Report - Capstone

Serves as the culminating experience, where learners manually compute single-ended and double-ended fault locations, modify scripts for Common Format for Transient Data Exchange (COMTRADE) -based automation, and compile analytical results into a professional event summary report. This capstone integrates technical diagnosis, regulatory context, and communication standards, mirroring field reporting practices used by utilities and engineering

firms. Industry interviews with technology vendors and field engineers reinforce expectations for professional documentation and decision support.

Across all twelve units, the Industry Interview Series (Section C) embeds practitioner insights from fault analysts, substation engineers, generation plant operators, transmission and distribution field staff, system operators, data communications specialists, software providers, and protection equipment vendors. This structure ensures that learners not only develop analytical proficiency but also gain exposure to the organizational roles, workflows, and professional expectations that shape real-world fault analysis and power system operations.

Instructional delivery

Instructional content is delivered through a combination of recorded lectures, interactive simulations, and guided exercises. Industry professionals contribute domain-specific insights through guest modules and case walkthroughs, while academic faculty provide theoretical framing and assessment oversight. This blended approach supports consistency in technical rigor while preserving alignment with field-level practice.

Academia–industry collaboration model

Co-development process

The curriculum was developed through an iterative co-design process involving academic faculty and practicing engineers. Initial learning objectives were informed by industry interviews and job task analyses. Draft modules were reviewed by both academic and industry advisory groups to ensure technical accuracy, pedagogical coherence, and operational relevance. The collaboration model also enables academic and industry partners to focus on their respective strengths. Academic contributors emphasize theoretical rigor and structured pedagogy, while industry experts provide operational context, real-world case studies, and workflow alignment. This complementary approach ensures that foundational concepts remain robust while maintaining direct relevance to field practices.

Feedback and continuous improvement

An embedded feedback loop enables learners and industry partners to provide structured input following each program cycle. This feedback informs content updates, case study selection, and adjustments to technical depth and pacing, supporting continuous alignment with evolving industry practices.

Assessment and evaluation strategies

Assessment is designed to evaluate learner development across conceptual, technical, perceptual, and workforce readiness dimensions through a structured framework summarized in Table 1. The evaluation approach integrates formative learning checks, performance-based tasks, and stakeholder feedback to provide a holistic view of program effectiveness.

Table 1. Assessment Framework for the Fault Analysis Certificate Program

Assessment Dimension	Instrument	Evidence Collected	Purpose
Conceptual understanding	Embedded quizzes	Quiz scores, concept mastery trends	Verify theoretical foundation
Applied fault analysis skills	Simulation-based assignments and quizzes	Accuracy of waveform interpretation, workflow execution	Measure technical competency
Learner confidence	Pre/post self-efficacy survey	Confidence gains in analysis and reporting tasks	Assess perceived skill development
Employer perspective	Supervisor feedback and interviews	Job-readiness indicators and onboarding efficiency	Validate industry relevance

Conceptual understanding is assessed through embedded quizzes distributed across instructional units, enabling monitoring of concept mastery and identification of areas requiring reinforcement. Applied fault analysis competency is evaluated using simulation-based assignments and targeted quizzes that require learners to interpret waveform data, execute analysis workflows, and demonstrate accurate fault classification using industry-standard tools. These performance-based activities emphasize authentic problem-solving and workflow execution reflective of professional practice.

To capture perceived skill development, pre- and post-program self-efficacy surveys measure changes in learner confidence related to disturbance analysis, technical reporting, and navigation of fault analysis processes. Complementing these learner-centered measures, employer perspectives are incorporated through supervisor feedback and structured interviews that examine indicators of job readiness, including independent use of disturbance records, quality of analytical reasoning, and efficiency in onboarding.

Together, these complementary assessment elements establish a multi-source evidence base for evaluating learning outcomes and workforce relevance, consistent with ecosystem-based and project-oriented engineering education models [8], [9].

The Fault Analysis Certificate Program is scheduled to launch in March 2026. Assessment data, including learner performance on simulation-based assignments, self-efficacy survey outcomes, and employer feedback, will be collected at the conclusion of the program in May 2026. This data will be incorporated into the final manuscript to provide initial evidence of learning outcomes and workforce readiness impacts.

Implementation and early observations

Participant profile

Participants include advanced students in engineering programs and practicing professionals seeking reskilling or advancement. The diversity of technical backgrounds necessitated careful

calibration of content depth and pacing, as well as explicit articulation of prerequisite knowledge.

Employer perspective and program effectiveness

As the program enters its initial deployment phase, participating utilities and engineering firms have collaborated in defining evaluation metrics to assess workforce readiness outcomes following the first cohort. Employers have identified onboarding time for engineers in protection and operations teams, independent use of disturbance records and relay coordination tools, and the quality of technical communication with operations and compliance staff as primary performance indicators to be assessed through post-completion surveys and supervisor interviews.

In addition, planned qualitative interviews will examine the perceived value of the virtualized DFR environments and anonymized, real-world case studies in replicating field conditions and supporting the transition of participants into productive operational roles. Employers have further proposed using the capstone event summary report as a structured proxy for regulatory and internal documentation tasks, enabling supervisors to evaluate job-relevant competencies prior to full deployment in real-world settings.

Beyond technical skill development, formal certification provides an important sense of structure, recognition, and professional identity that is not always achieved through informal mentoring alone. While one-on-one mentorship remains valuable, the certificate serves as a visible milestone that signals competency progression and supports both individual confidence and organizational workforce development.

This evaluation framework is informed by project-based and ecosystem-oriented engineering education research, which links authentic, industry-embedded learning environments to improved onboarding efficiency and early-career professional performance [8], [9].

The Fault Analysis Certificate Program is scheduled to launch in March 2026. Preliminary assessment results, including learner performance on simulation-based assignments, self-efficacy survey outcomes, and employer feedback, are to be collected at the conclusion of the program in May 2026. These data will be incorporated into the final manuscript to provide initial evidence of learning outcomes and workforce readiness impacts. This staged evaluation approach enables the present study to document program design and implementation while ensuring that the final version reflects empirically grounded assessment insights from the inaugural cohort.

Because the inaugural cohort is underway, the present manuscript emphasizes program design and evaluation planning, with quantitative outcome analysis to be incorporated in the final submission.

Discussion on replicability and sustainability

The modular, unit-based structure of the Fault Analysis Certificate Program enables straightforward replication across academic institutions, utility training centers, and corporate professional development programs. Because each competency domain is designed as a self-contained instructional block, partner institutions can deploy the full certificate as a standalone credential or embed selected units within existing degree programs, continuing education offerings, or internal utility training pipelines. This flexibility supports alignment with regional

workforce needs, regulatory environments, and organizational priorities while preserving a consistent pedagogical framework.

Scalability is further supported through the use of virtualized analysis environments and cloud-enabled simulation platforms. These infrastructures allow the program to accommodate geographically distributed learners and to increase enrollment without proportional growth in physical laboratory resources. Standardized, anonymized case libraries and software-based diagnostic workflows enable consistent learning outcomes across cohorts and partner institutions.

Long-term sustainability is reinforced through formal industry advisory participation, which guides periodic curriculum review and ensures continued alignment with evolving grid technologies, protection standards, and regulatory frameworks. The certificate is also designed as a stackable, competency-based credential that can articulate into graduate coursework, professional licensure preparation, or corporate career ladders, supporting institutional adoption and long-term investment [7], [8].

Conclusion

The Fault Analysis Certificate Program demonstrates how sustained academia–industry collaboration can produce career-focused training that bridges the gap between theoretical education and real-world practice. By integrating applied learning, flexible delivery, and continuous industry input, the program provides a replicable model for workforce development in power engineering and related technical domains. The incorporation of industry-grade simulation tools, real-world fault scenarios, and a multi-dimensional assessment pipeline enables systematic evaluation of learner development across conceptual understanding, applied analytical skills, confidence growth, and employer-perceived readiness.

As modern power systems continue to evolve through increased penetration of power-electronic interfaces, advanced protection schemes, and data-driven operational practices, the demand for engineers skilled in fault analysis and system diagnostics will continue to grow. Programs that combine academic rigor with operational relevance and structured evaluation frameworks offer a scalable pathway for workforce development in evolving power system environments.

Future Work

Future work will expand the evaluation framework through longitudinal tracking of participant outcomes, including retention of analytical competencies, progression into protection and operations roles, and employer-reported impacts on onboarding efficiency. Additional data from subsequent cohorts will enable quantitative analysis of learning gains and comparative studies across participant backgrounds, supporting refinement of instructional design and assessment instruments. Multi-institutional deployment and cross-industry collaboration will provide opportunities to validate the program’s scalability and to examine how structured assessment pipelines can inform workforce development strategies in evolving power system environments.

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